COMPARING RESULTS OF AIRPORT CONCRETE SLABS DESIGN USING DAMAGE MODELS OF FAARFIELD TO MEPDG CONCRETE FATIGUE MODEL

By:
Cauê Bin and José Balbo
School of Engineering
University Of Sao Paulo
Av. Prof. Luciano Gualberto 380 – Travessa 3
Sao Paulo, CEP 05508-070
Brazil
Phone: +55 (11) 3091-5750; Fax: +55 (11) 3091-5716
caue.bin@usp.br
jotbalbo@usp.br

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INTRODUCTION

The current but still new design method for airport pavements of Federal Aviation Administration (FAA [1]) deals with the pavement damage by using a two-stage degradation model for the concrete slabs which have been completely rewritten. Such models were calibrated on the basis recent data of failure of new analysis of full-scale test data, using data points from the National Airport Pavements Test Facility (NAPTF) concrete pavement test acquired in 2004.

Now a days is being discussed the need of a “three-stage” model of failure. This one inserts a new and very important stage, with starts at the crack initiation and end at the first full-depth crack. But FAARFIELD is using the two-stage model, with some modifications for stabilized bases. The two-staged model consists into two clear periods, with the first beginning when the slabs are new and ending at the developing of first full-depth crack (Brill [2]). The second period starts at this point and goes until the end of pavement service life. In other words, the three-stage model subdivides the first stage into two smaller ones, whose effects are different in the pavement life.

The degradation model in question uses the Structural Condition Index (SCI) and is directly related to the traffic coverage of airplanes during the design period; such as an index is field-performance related taking into account distresses like corner breaks, linear cracks, shattered slabs, shrinkage cracks and joint and corning spalling, presenting at most three levels of severity.

Such approach, clearly semi-empirical, differs from traditional fatigue degradation approach used widely by road agencies for the design of concrete pavements, when concrete fatigue transfer-functions refer to a first and catastrophic crack. This paper deals with such a difference for the crack criteria, were it seeks to understand the different results on using a concrete fatigue transfer function proposed by AASHTO [3], namely MEPDG criteria, for the fatigue design of airport concrete slabs alternatively to the 2-stage FAA criteria. The fatigue damage related to transverse crack performance model of MEPDG is not analyzed within this paper since coverage models in this highway pavement guide are far different from FAA design guide. Hence, it is not employed for the analysis the concept of incremental damage due to loss of original materials characteristics resulting from wheel-climate action over pavements along the months and years of service.

The purpose of comparison of FAA failure model to MEPDG fatigue semi-empirical transfer function was carried out by simulating the commercial airplane traffic mix actually obtained from JFK airport data for the period from 2000 to 2001 (one year full data) provided by Keegan, Handojo and Rada [4]; the design using FAARFIELD simulated a design period of 20, 30 and 40 years and a pavement base layer of crushed aggregate with 8 in (30 cm) was fixed; the subgrade was taken with modulus of subgrade reaction (k) of 361.1 pci (100 MPa/m), the maximum available at the software used.

The stresses due to each airplane of the traffic mix were achieved from the file NikePCC.out of FAARFIELD software allowing the simulation of the MEPDG fatigue model for a taken concrete flexural strength of 569 psi (4 MPa). The results states the differences in terms of life span using the road pavement fatigue model to the design period fixed for FAARFIELD pavement design.

Detailed air traffic mix is desirable to make a better simulation in FAARFIELD program, which has a vast database of aircrafts. But, the traffic mix found is an approximation of the real JFK Airport 2000-2001 traffic (Keegan, Handojo and Rada [4]). This occurs because the frequency of many aircraft types is very low once over 350 different aircraft operations were found there. It was simplified into seven aircraft groups, each with a representative aircraft, explained more detailed later.

AIRCRAFT MIX AT JFK

Keegan, Handojo and Rada [4] presented a paper discussing the need for accurate traffic data in pavement management which is very important to control the damage, making simulations to improve the maintenance, design and evaluation.

In that case, the data of JFK traffic mix is based on an approximation considering the annual volume data compiled from Port Authority database. The 12-month period selected was September 1, 2000 to August 31, 2001, and the total traffic volume was 337,760 aircrafts. The large number of aircraft designators, more than 350, often representing only subtle differences, was condensed into seven representative groups. Each group is then represented by one aircraft: the most commonly occurring type at JFK, as shown in Table 1. The criteria to group similar aircraft "*since this is to support pavement management, were based on the basis of their weight and gear characteristics, preserving the concept of operations*" is as reported in Keegan, Handojo and Rada [4].

Table 1.
2001 Representative Aircraft Mix and Annual Volume – JFK.

Representative Aircraft	Gear Type	MGTOW (lbs.)	2001 Mix (%)	2001 Mix (Annual Volume)[a]
B-747-400	Double Dual Tandem	> 750,000	10.7	36,140
B-777-200	Triple Tandem	> 660,000	1.8	6,080
MD-11	Dual Tandem	≥ 500,000	3.8	12,835
B-767-300	Dual Tandem	350,001 to 499,999	26.7	90,182
B-757-200	Dual Tandem	< 350,000	11.7	39,518
A-320-200	Dual	≥ 60,000	22.1	74,645
SF-340	Dual or Single	< 60,000	23.2	78,360

[a]based on Keegan, Handojo and Rada [4], Table 5.

It is important to remember that for design using FAA procedure is required to consider only the number of annual departures operations of any airplane type, which is essentially the worst case in terms of Maximum Gross Take-Off Weight (MGTOW). Therefore, in this case, to make the worse possible situation, the whole annual volume (aircraft movements) will be considered as departure traffic mix.

Using only seven airplanes facilitates to input data on the software FAARFIELD. However, some of these aircrafts are not available at the database of the software; therefore the lacking aircrafts has been replaced by similar aircrafts at the database. Such differences are explained in the following.

AIRCRAFT MIX IN FAARFIELD

At this step the 2001 mix of JFK presented in Table 1 would be transferred to the software FAARFIELD. The unique assumption made is the annual volume would be equals to the annual departures, an input variable required to run the software. But in addition some issues were found: the aircrafts B747-400, B777-200, MD-11, A320-200 and SF-340 are not exactly named as here referred in the database of FAARFIELD. The solution was to change these airplanes to similar in MGTOW and Gear Type. Following this line, the substitutions made were: B747-400B Combi instead of B747-400; B777-200 by B777-200LR; MD-11 by MD11ER/MD11ER Belly; A320-200 by A320-200 Twin std.; and SF-340 by Sing Whl-60. As seen in Figure 1 these changes preserve the MGTOW condition and by clicking the button "View Gear" in the FAARFIELD software at lower right corner for each aircraft, the gear type was then checked and confirmed.

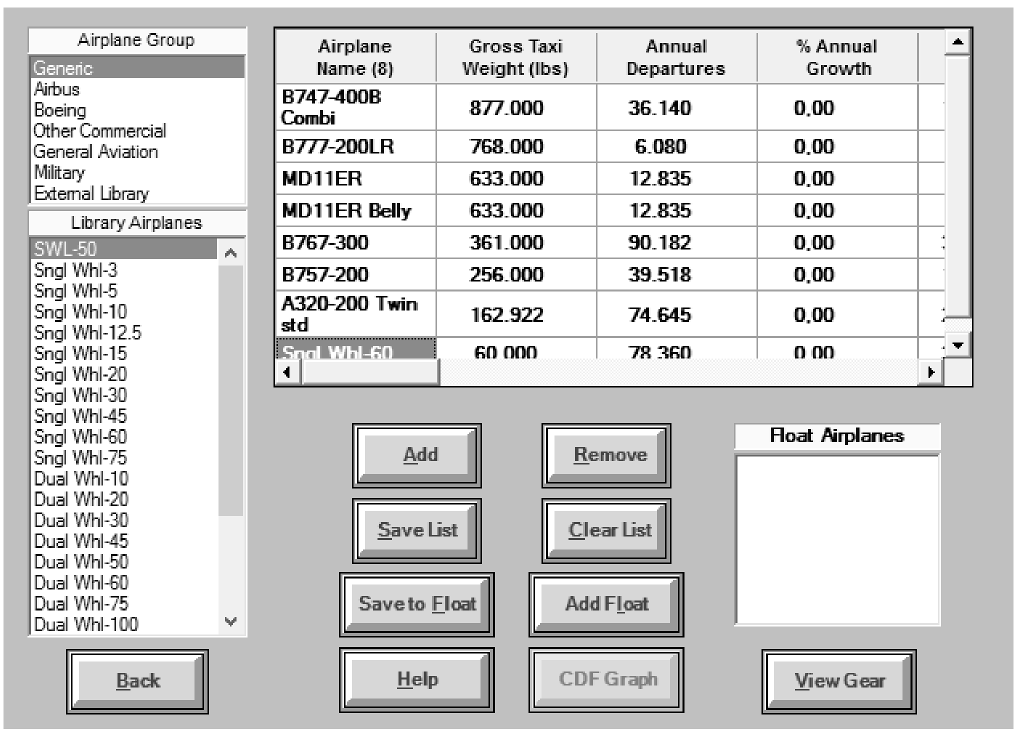

Figure 1. 2001 Representative Aircraft Mix of JFK on FAARFIELD.

It is worth note to highlight that the aircraft MD11ER is subdivided into two at FAARFIELD. As seen in Figure 1, with the MD11ER another "aircraft" was united, the MD11ER Belly. In another words, every time that the first airplane is selected, the second one goes to the mix likewise, compulsorily. That occurs because this aircraft has two landing gears, the main Two Dual Tandem and also a Dual Wheel, the last one responsible for the belly.

Another fact to take into account is that the software FAARFIELD considers that always 95% of Gross Taxi Weight is supported by the main gear and the 5% left is supported by the nose gear.

USING THE SOFTWARE FAARFIELD TO ACHIEVE CRITICAL STRESSES

As the main objective of this paper is to collate FAARFIELD design results (in terms of critical stresses) to MEPDG concrete fatigue model, understanding the differences on the number of aircraft operations forecasted for each case, the study starts using the software FAARFIELD with the pavement and aircraft traffic parameters above specified to reach the computation of critical stresses induced by each airplane of the traffic mix. Such traffic mix was chosen to make a real simulation of comparative results (Mix for 2000-2001 JFK).

The pavement layers and its parameters as inputs to FAARFIELD, in addition to the traffic mix, were: the base of the pavement (P-209 Crushed Aggregate) with 8 in (30 cm) thickness, which modulus value is set automatically by the program; the modulus of subgrade reaction is 361.1 pci (100 MPa/m); concrete flexural strength of 569 psi (4 MPa). The design periods were the only not constant variable, with three different values, 20, 30 and 40 years.

The output data for the critical flexural stresses on slabs, at the three different simulations, were rescued from the software folder, as the file named NikePCC.out, as simplified shown in Figure 2. The output values are the thickness of the concrete slab and the tensile stress in bending caused by each aircraft.

The “layer number” 1, 2 and 3 indicates, respectively, PCC Slab, P-209 Crushed Aggregate and subgrade and it is followed by the thickness calculated by the software or indicated by the designer. The number that follows the phrase “PCC SLAB HOR STRESS” indicates the stress due to each aircraft of the mix. To allow the software to produce the output file is required to uncheck “No out file” in “Options” section.

After repeat this test for three times, changing only the design period (20, 30 and 40 years), the output data from NikePCC.out were recorded and synthesized here in Table 2. To calculate the number of departures during 20, 30 and 40 years were supposed 0% of annual growth. The stress caused by each airplane and the concrete flexural strength is named σ_{tf} and Modulus of Rupture (MR), respectively.

Analyzing the output data is possible to find the aircraft whose impact is greater on the pavement. In other words, the airplane responsible for the higher stress (σ_{tf}) at the bottom of the PCC slab, as seen in Table 2, is the MD11ER Belly. As previously explained, the aircraft is actually the MD11ER, which in FAARFIELD software was subdivided into two, as having two landing gears, as seen in Figure 3. The gear responsible for the “belly” of MD11ER is a Dual Wheel model, which causes higher stress in concrete because of the concentration of Gross Weight (GW) in a little area of the slab surface. The FAARFIELD database for MD11ER reports that 39% of GW are supported by each Dual Tandem and 17% are carried by the Dual Gear responsible for the belly, totalizing 95% (39% + 39% + 17%); the remaining 5% is carried by the nose gear.

Layer No.	Thickness (in)	Elasticity Modulus	Poisson's Ratio	Interface Condition
1	18,69	4.000.000,0	0,150	0,000000
2	8,00	79.447,8	0,350	1,000000
3	0,00	49.999,7	0,400	1,000000

Aircraft No. 1 B747-400B Combi Wing
PCC SLAB HOR STRESS
227,0837

Aircraft No. 2 B777-200LR
PCC SLAB HOR STRESS
250,3618

Aircraft No. 3 MD11ER
PCC SLAB HOR STRESS
232,7576

Aircraft No. 4 MD11ER Belly
PCC SLAB HOR STRESS
262,2914

Aircraft No. 5 B767-300
PCC SLAB HOR STRESS
187,9032

Aircraft No. 6 B757-200
PCC SLAB HOR STRESS
169,543

Aircraft No. 7 A320-200 Twin std
PCC SLAB HOR STRESS
208,3812

Aircraft No. 8 Sngl Whl-60
PCC SLAB HOR STRESS
108,645

Aircraft No. 9 B747-400B Combi Body
PCC SLAB HOR STRESS
227,0837

Figure 2. C:\Program Files (x86)\FAA\FAARFIELD\NikePCC.out file with JFK 2001 Mix and design life of 20 years.

Table 2.
Stress caused due to each aircraft at JFK 2001 Mix for 20, 30 and 40 years of design life.

Aircraft	Departures				σ_{tf} (MPa)			MR (MPa)
	annual	20 years	30 years	40 years	20 years	30 years	40 years	
B747-400B Combi	36,140	722,800	1,084,200	1,445,600	1.5965	1.5667	1.5466	
B777-200LR	6,080	121,600	182,400	243,200	1.7600	1.7384	1.7073	
MD11ER	12,835	256,700	385,050	513,400	1.6364	1.6060	1.5843	
MD11ER Belly	12,835	256,700	385,050	513,400	1.8441	1.8034	1.7758	4.00
B767-300	90,182	1,803,640	2,705,460	3,607,280	1.3211	1.2956	1.2786	
B757-200	39,518	790,360	1,185,540	1,580,720	1.1920	1.1828	1.1722	
A320-200 Twin std	74,645	1,492,900	2,239,350	2,985,800	1.4651	1.4311	1.4081	
Sngl Whl-60	78,360	1,567,200	2,350,800	3,134,400	0.7639	0.7445	0.7315	

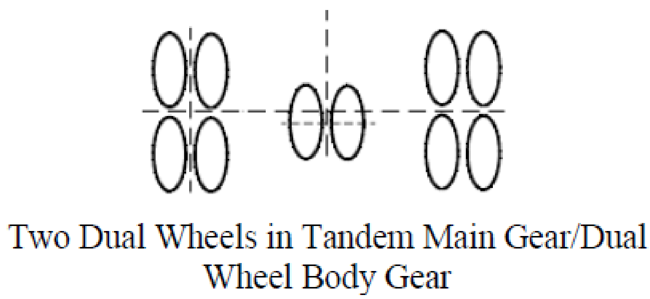

Figure 3. Main Gear of MD11ER and Body Gear of MD11ER Belly.

MEPDG JOINTED PLAIN CONCRETE PAVEMENT DESIGN PROCEDURE

The AASHTO design method [3] provides a fatigue transfer function for dimensioning the number of admissible cycles of loads affordable by plain concrete slabs before it cracks. But, different from the model used by FAARFIELD, this one is one-staged. This means that every cycle implies the same damage in the pavement, no matters the residual structural condition of the slab, if one take the fatigue model transfer function alone without any regard to fatigue damage models of MEPDG.

The general design procedure for defining slab thickness in MEPDG is given in Figure 4. Note that for the design process it is necessary a fatigue transfer function to predict top-down and bottom-up cracking based on stresses levels on slabs (top and bottom stresses). The design is dependent on the *avant* fixed tolerable cracking level for the end of design period, what is variable from one road agency to another on the basis of local experience, being usual values between 10% and 45% [5]; it is worth nothing that the lesser the tolerable cracking level, the most robust design is attained in terms of slab thickness.

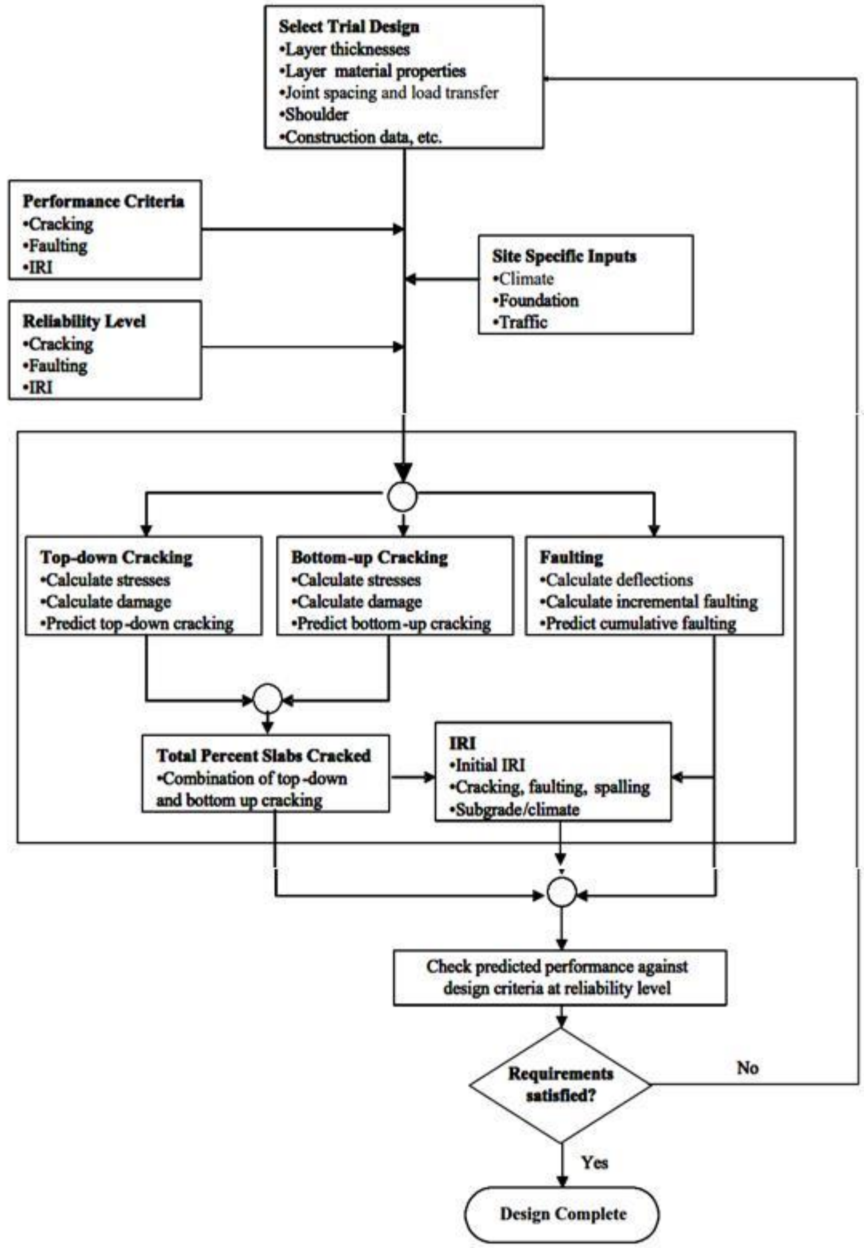

Figure 4. MEDPG design procedure (Source: NCHRP [5]).

Percent of cracking level (*CRK*) in MEPDG is reached through a function relating the fatigue damage (*FD*) to the top-down and bottom-up cracking, accordingly (graphical view in Figure 5):

$$CRK = \frac{1}{1 + FD^{-1.68}}$$

For computation of the total amount of cracking (*TCRACK*) is required to consider both (in fractions) predicted amounts of bottom-up cracking ($CRK_{Bottom\text{-}up}$) and top-down cracking ($CRK_{Top\text{-}down}$) as follows:

$$TCRACK = \left(CRK_{Bottom-up} + CRK_{Top-down} - CRK_{Bottom-up} \times CRK_{Top-down}\right) \times 100\%$$

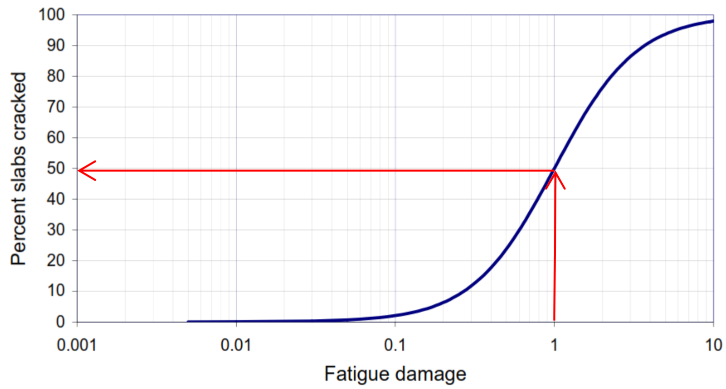

Figure 5. MEDPG conversion function between fatigue damage and transverse crack level (Source: NCHRP [6]).

The fatigue damage, in turn, is dependent on a fatigue transfer function which is typically semi-empirical since defined based on the performance of LTPP and FHWA RPPR field sections (total amount of 196 samples) located in 24 states in US; such a model was calibrated for a number of load cycles to fatigue when failure corresponds to 50% of cracked slabs at the observed sections (see Figure 5), and uses an incremental calibrated procedure as follows:

$$\log(N_{i,jk,l,m}) = 2.0 \times \left(\frac{MR_i}{\sigma_{i,jk,l,m}}\right)^{1.22} + 0.4371$$

Where parameters stand for:

MR_i = concrete modulus of rupture at age i;
$\sigma_{I,j,k,l,m}$ = critical stress level at age i, month j, axle k, load level l and temperature differential m;
$N_{I,j,k,l,m}$ = allowable number of axle repetitions to failure (fatigue) for age i, month j, axle k, load level l and temperature differential m.

Regarding to coverage due to lateral wander of wheels, for any case of level of reliability for traffic (I, II or II) input data, the characteristics at wheelpath where taken as follows: lateral wander of 0.457 m, lateral wander standard deviation of 0,254 m and design lane width of 3.66 m [6]. The effects of lateral wander are considered along with the above fatigue failure model using numerical integration schemes [6]. The fatigue damage for the pavement is then calculated using the multiplicative model:

$$FD^*_{ij} = P(COV_j) \times FD_{ij}$$

Where parameters stand for:

FD^*_{ij} = fatigue damage at location i (critical point) related to the fraction of traffic passing though point i;

FD_{ij} = fatigue damage at location i (critical point) related to the fraction of traffic passing though point j;

$P(COV_j)$ = probability of traffic passing to point j, assumed as a normal distribution.

Eventually, the fatigue damage is computed considering the actual design (n) and the allowable (N) number of load repetitions by means of Miner's hypothesis:

$$FD = \sum \frac{n_{i,j,k,l,m}}{N_{i,j,k,l,m}}$$

FAARFIELD FAILURE MODEL

The software issued by FAA [1] uses a two-staged degradation model. In FAARFIELD, the condition of the pavement is measured by Structural Condition Index (SCI), which is directly related to the traffic coverage of airplanes during the design the period. Added to this, the software uses the pass-to-coverage (P/C) ratio and cumulative damage factor (CDF). As the intent of FAARFIELD is to give a direction in the design of airport pavements, those aspects are very important to calculate the necessary thickness of the slab.

The first concept, pass-to-coverage ratio, takes into account the lateral distribution (also known as airplane wander) of wheel-paths on runways and taxiways (which is modeled by a statistically normal distribution). In this case studied (rigid pavements), one coverage occurs when maximum stress is observed at the bottom of the slab and passes are the number of aircraft movements. The major difference when comparing this procedure to MEPDG (as this method is applied on road traffic), the lateral distribution is considered as aforementioned at small displacements compared to aircraft landing gears. Therefore, as the damage is higher, is to be expected that when using this method, the number of allowable cycles is lesser than proposed in FAARFIELD if one take the fatigue model alone.

The cumulative damage factor is the amount of the Portland cement concrete (PCC) slab fatigue life used by each aircraft. "*It is expressed as the ratio of applied load applied repetitions to allowable load repetitions to failure",* as reported in FAA [1]. When it sums to 1.0, it means that the aircraft mix will be attended by the pavement designed. For each airplane and with no growth on annual departures, CDF is given by the expression below.

$$CDF = \frac{number\ of\ applied\ load\ repetitions}{number\ of\ allowable\ repetitions\ to\ faliure}$$

As presented by Brill [2], the deterioration of SCI is modeled approximately by the linear function of the logarithm of coverages: *"SCI just begins to diminish from its initial level of 100, is defined as C_O. The SCI level associated with C_O is denoted 100. The number of coverages to complete failure, defined as the loss of all slab integrity or SCI = 0, is C_F. The path from C_O to C_F is an assumed linear function of log (C)."*

The SCI on rigid pavement failure model is given by the formula below, which is function of coverages C, concrete MR, tensile stress in bending (σ_{tf}) and some parameters, which are obtained from full-scale tests performed at NAPTF:

$$SCI = \frac{DF - a - \left[F_s \times b + \left(\frac{d - F_s \times b}{100}\right) \times SCI\right] \log C}{e}$$

Where: DF = design factor = MR/σ_{tf}
C = coverages
F_s = stabilized base compensation factor
a, b, d, e = parameters

COMPARING DEPARTURE MIX (FAARFIELD) WITH ADMISSIBLE CYCLES (MEPDG)

Following both analysis procedures (FAA and MEPDG) and using the stress due to each aircraft (σ_{tf}) during different design life periods (20, 30 and 40 years) was possible to achieve the results in terms of admissible cycles as shown in Table 3. The results point out that the fatigue model of MEPDG allows, for the stresses generated by FAARFIELD, more load repetitions than the anticipated ones (JFK mix).

Table 3.
Number of admissible cycles by MEPDG and departures imposed by the JFK 2000-2001 mix.

Aircraft	Departures by JFK 2000-2001 mix			Admissible cycles (MEPDG)		
	20 years	30 years	40 years	20 years	30 years	40 years
B747-400B Combi	7.23E+05	1.08E+06	1.45E+06	3.72E+06	5.17E+06	6.51E+06
B777-200LR	1.22E+05	1.82E+05	2.43E+05	7.64E+05	9.24E+05	1.23E+06
MD11ER	2.57E+05	3.85E+05	5.13E+05	2.45E+06	3.37E+06	4.25E+06
MD11ER Belly	2.57E+05	3.85E+05	5.13E+05	3.82E+05	5.29E+05	6.67E+05
B767-300	1.80E+06	2.71E+06	3.61E+06	1.46E+08	2.24E+08	3.02E+08
B757-200	7.90E+05	1.19E+06	1.58E+06	1.58E+09	1.91E+09	2.39E+09
A320-200 Twin std	1.49E+06	2.24E+06	2.99E+06	1.77E+07	2.80E+07	3.86E+07
Sngl Whl-60	1.57E+06	2.35E+06	3.13E+06	3.27E+15	9.89E+15	2.15E+16

A first analysis was carried out just taking individually comparison of the number of departures from JFK 2000-2001 mix and the number of allowable cycles by MEPDG (fatigue transfer function alone) making it possible to verify for any aircraft whether the mix design traffic was met or not, as shown in Table 4. The differences are always positive considering each aircraft separately.

Table 4.
Difference between allowable MEPDG cycles (fatigue transfer function alone).and actual departures from JFK 2000-2001.

Aircraft	Differences		
	20 years	30 years	40 years
B747-400B Combi	3.00E+06	4.09E+06	5.06E+06
B777-200LR	6.42E+05	7.42E+05	9.84E+05
MD11ER	2.19E+06	2.98E+06	3.74E+06
MD11ER Belly	1.25E+05	1.44E+05	1.54E+05
B767-300	1.45E+08	2.22E+08	2.98E+08
B757-200	1.58E+09	1.91E+09	2.39E+09
A320-200 Twin std	1.62E+07	2.57E+07	3.56E+07
Sngl Whl-60	3.27E+15	9.89E+15	2.15E+16

CONSUMPTION OF FATIGUE RESISTANCE BY MEPDG

To evaluate and compare the whole aircraft mix departures of JFK with the admissible cycles by MEPDG (fatigue function alone) is necessary to introduce the concept of consumption of fatigue resistance by the n^{th} aircraft (*CFRn*), where the consumption of fatigue resistance by the whole traffic mix is *CFR*.

$$CFR_n(\%) \quad = 100 \times \left(\frac{N_p}{N_f}\right)$$

Where: $CFR_{n\%}$ = Consumption of fatigue resistance by the n^{th} aircraft
N_p = Number of operations to date
N_f = Number of admissible cycles to failure

$$CFR\ (\%) \quad = \sum_{1}^{n} CFR_{n\%}$$

When the *CFR* assumes the value of 100% it means that (theoretically) the concrete slab went under fatigue by a full-depth and catastrophic crack, what makes the remaining life dropping to zero, when the approach is not based on semi-empirical field calibrated damage model. In other words it is expected that the *CFR* assumes the value of 100% when the service life got reached (as the FAARFIELD calculates the thickness necessary to make the pavement meet the traffic for the design life and fatigue when the service life is over). But if *CRF* exceeds 100% it means that the catastrophic crack shall happen before the expected life leading to an early fatigue condition. Following this propose, as showed in Table 5, it was calculated the *CFRn* due to each aircraft for each design life period and the total *CFR* as well.

Table 5.
Consumption of fatigue resistance by the nth aircraft (*CFRn*) with designed life and *CFR* total.

Aircraft	*CFRn* (%)		
	20 years	30 years	40 years
B747-400B Combi	19.41	20.96	22.21
B777-200LR	15.92	19.73	19.82
MD11ER	10.48	11.44	12.07
MD11ER Belly	67.24	72.76	76.94
B767-300	1.23	1.21	1.20
B757-200	0.05	0.06	0.07
A320-200 Twin std	8.41	8.01	7.74
Sngl Whl-60	0.00	0.00	0.00
CFR	122.75	134.17	140.04
Years before fatigue (MEPDG)	16.29	22.36	28.56

COMPARING DESIGNED LIFE (FAARFIELD) WITH SERVICE LIFE BY MEPDG

Is possible to verify that individually none of the JFK mix aircrafts consume more than 100% of *CFR*. As the total of *CFR* was above 100% (Table 5) for any design period it means that the slabs, according to the MEPDG fatigue model, will survive less than the forecasted life in FAARFIELD (20, 30 and 40 years). Then, the next step is to determine the service life of the pavement by the MEPDG. In order to do that it is necessary to discovery when the *CFR* reaches 100%, what can be done by the following rule:

$$L_{MEPDG} = \left(\frac{100}{CFR}\right) \times DL_{FAARFIELD}$$

Where: L_{MEPDG} = Service life by MEPDG fatigue function;
$DL_{FAARFIELD}$ = Designed life in FAARFIELD;
CFR = Consumption of fatigue resistance by the whole mix.

In Table 6 is shown the service life calculated by the MEPDG in comparison with the designed life in FAARFIELD, considering the first hypothesis presented at introduction (was calculated the necessary thickness of PCC slab and the critical stress caused due to each aircraft at JFK 2000-2001 traffic mix for 20, 30 and 40 years periods). Hence, from results presented in Table 6 it is observed that by the MEPDG fatigue function the pavement service life is lesser than designed assumed. Moreover, according to the life percentage's the situation gets worse as the designed life is larger.

Table 6.
Design life in FAARFIELD compared to service life calculated according MEPDG fatigue function.

Designed Life in FAARFIELD	20 years	30 years	40 years
Service Life by MEPDG	16.29 years	22.36 years	28.56 years
Service Life/Designed Life (%)	81.45	74.53	71.40

CONCLUSIONS

Is important to highlight the differences between FAARFIELD and MEPDG to understand why the results of the second one were above the expectations for the first one. Added to the fact that MEPDG fatigue model preserves one-staged concept, the FAA method takes into account the lateral wander of the aircraft traffic as well the pass-to-coverage ratio. It is evident that wander distribution of aircraft wheels in airport taxi and landing lanes is larger than in the road lane case. The meaning of such a difference is the critical point at a road pavement being subjected to more concentrated and higher stresses (one should consider that even using similar concrete mixtures the airport concrete slab is thicker than highway slabs).

The software developed by FAA considers that not in every cycle the critical stress (σ_{tf}) caused by each aircraft occurs in the slab. This is so due to lateral wander of main gears ("*an aircraft seldom travels in a perfectly straight path or along the exact the same path as before*", FAA [1]) and many times the stress in concrete slab is less than the maximum one provided by NikePCC.out file, as shown in Table 2. This means that for the presented analysis using MEPDG fatigue function it was not taken into account aircraft gears wander and for every load cycle the same maximum stress (σ_{tf}) was imposed; the road traffic travels following almost the same path frequently as the lane width is very narrow.

However, the probable main reason to make the service life calculated by MEPDG be about 80% of designed life (as seen in Table 6) is the one-staged fatigue model, herein arbitrarily considered, confronting with the two-staged damage calculation mode employed by FAARFIELD. For the analysis presented several different fatigue transfer functions could be used; but comparing FAA to MEPDG can bring their parallelisms also, since MEPDG is unique in term of road slabs.

In the software FAARFIELD, the pavement is considered in service life even after the first full-depth crack (as shown in Figure 4) and the slab degradation model indicates that it fatigues after it is under an imposed condition in the Structural Condition Index. In other words, only after the SCI decreases to a prefixed value (this index starts to reduce only when the first full-depth crack happens) the concrete slab will go fatigue. This means that, by the degradation model of this software, the pavement will support loads even after the first full-depth crack, until the condition of the slab is too poor (due to other distresses besides the first crack) to support the loads of the aircraft traffic mix.

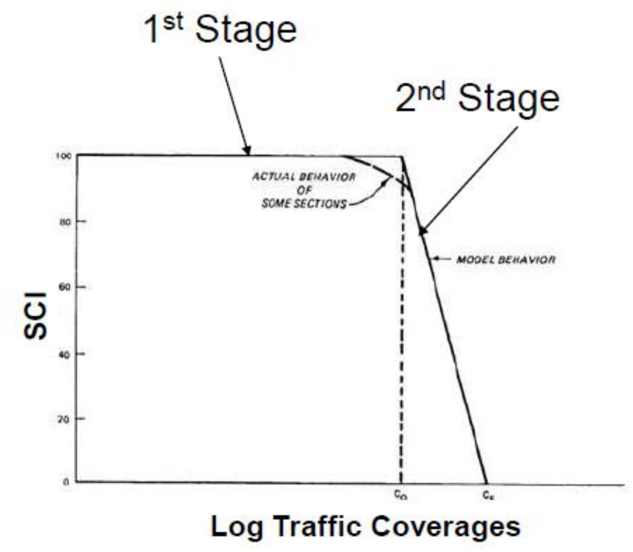

Figure 6. SCI versus number of cycles with indication of the stages periods (Source: Brill [2]).

MEPDG concrete fatigue model has another interpretation for pavement serviceability. For the design it shall be fixed the acceptable percent of transverse cracks in the design session; this tolerance may vary between 10% (stronger design) to 50% (weaker design). And the concept of fatigue is not retained for one first crack criteria as supposed by the fatigue function alone; it is expanded to consider the bottom-up and top-down cracks associated with a probabilistic analysis of wander behavior of the wheels.

However, when considering one-staged fatigue models, as it is still being done in many countries, is to simply admit that service life ends at the developing of first full-depth crack. So, the second period (that starts at this point and goes until the end of pavement service life due to other reasons besides the first crack) is one of the main differences of these degradation models. In fact, the calibration of MEPDG took into account the survival of concrete pavements after the primary fatigue cracks and the lateral wander of wheels. On this view the methods are similar although it is important an improved analysis of the abridgement of FAARFIELD regarding edge stresses and lack of dowel bar load transfer at joints.

The NCHRP [6] explains that three types of variables affecting pavement behavior and slabs stress where used for the calibration of the fatigue damage model related to transverse cracking of slabs: (1) design features, namely, permanent curling and warping, slab length and dowels characteristics; (2) drainage and geometric properties as concrete short wave absorptivity, concrete infiltration (moisture), cross slope and length of drains path; (3) layers and materials properties, namely, layer position and material type, thickness and modulus of elasticity, flexural (in bending and split) and compressive strengths, ultimate shrinkage, unit weight, Poisson’s ratio, concrete coefficient of thermal expansion, thermal conductivity, heat capacity, concrete zero stress temperature. Some of these factors, as explicitly thermal gradients analysis are not allowed on current FAIRFIELD model, leaving therefore some points for future improvements.

As remarked during discussions on fatigue models in recent past [7] the use of analytical or numerical methods on calibration of fatigue models are important, as wheel position of loads over slabs. It is not directly possible to compare design methods considering damage models calibrated through different process. Such differences shall prevent us to use fatigue models developed under some specific conceptual approach within a design method using different stress analysis approach. This risk sometimes exists and even seduces design professionals on the search for economic benefits of alternative designs.

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